



If you can't get a bigger Target...

A Simplified Method To Predict Projectile Body Engraving

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Overview

- **Background**
- **Literature Search**
- **Force Model**
- **Engraving Model Description**
- **Engraving Model “Calibration”**
- **General Comparison of Constant & Gain Twist Tubes**
- **Conclusions**



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Why Model Body Engraving?

Body Engraving Leads To:

- Land Flattening
- Large Dispersion
- Increased Gas Blow-by

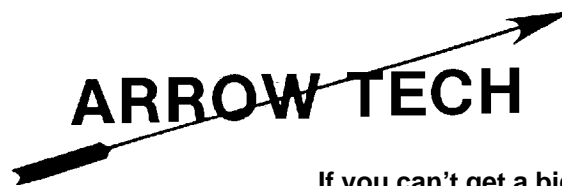
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- Resulting In Reduced Tube Life

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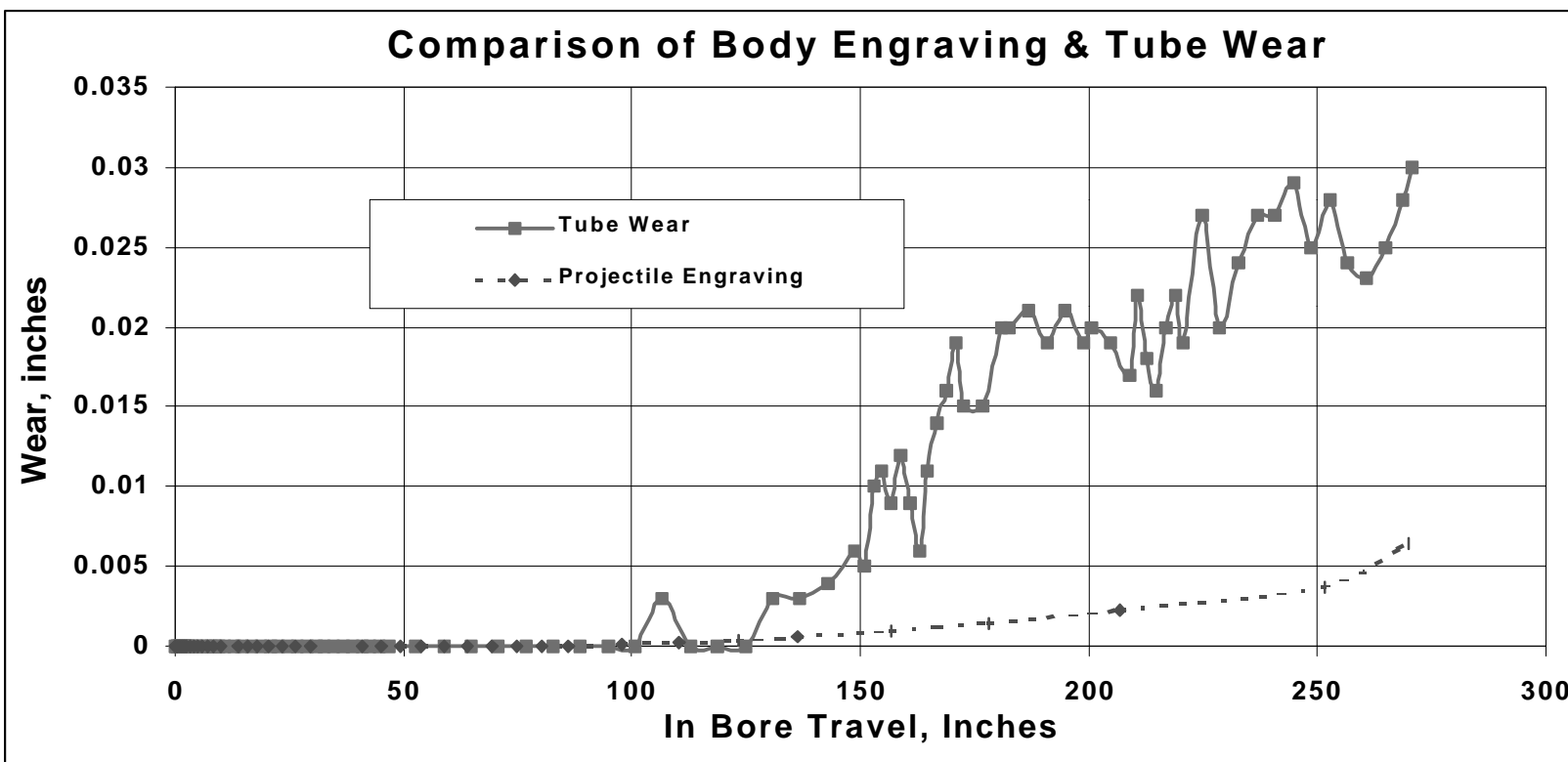
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Correlation of Body Engraving and Observed Tube Wear



- Tube Wear and Body Engraving Start At Similar Points



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Background

- **155mm Paladin vs. Crusader**
 - Muzzle Wear Increase With Constant Twist
- **30mm GAU-8/A**
 - Constant - Gain Twist W/ Thermally Expanded Tubes

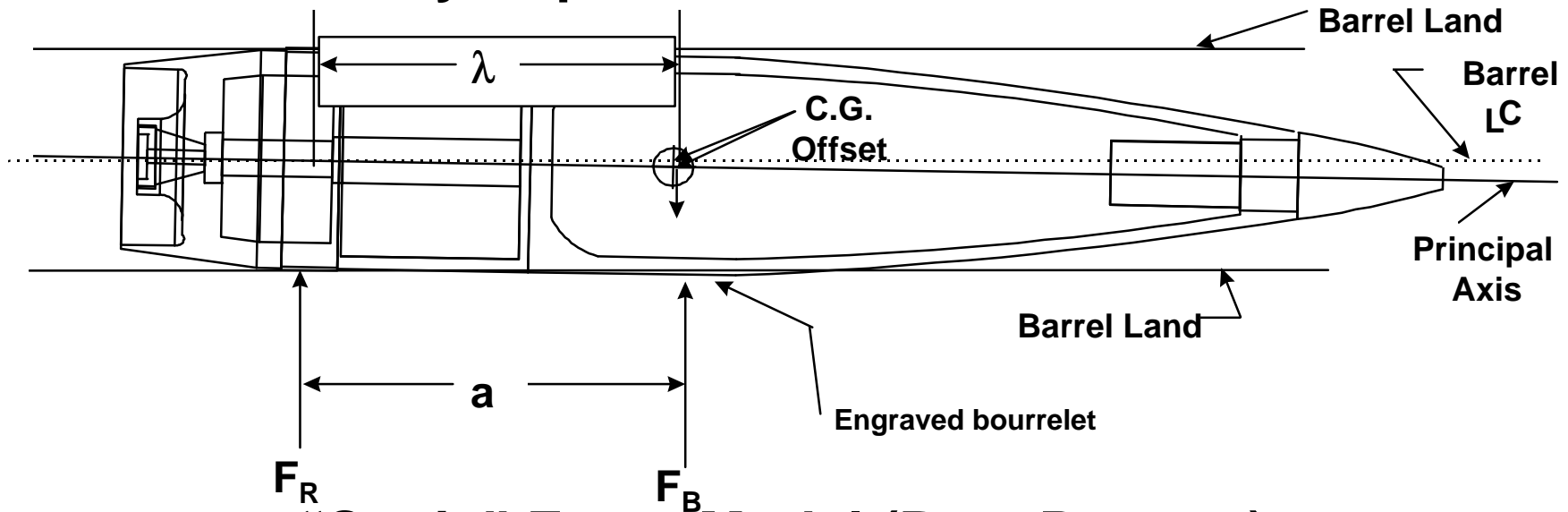


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Literature Search:

- In 175mm Howitzer, Body Engraving is Proportional to Volume of Copper Worn at Muzzle Exit (Implies Leak)
- Obturator Reduces / Eliminates Body Engraving
- Muzzle Wear & Body Engraving Are Related
- 155mm Fwd Bourrelet Force ~ 800 lbf / 0.001" @ 20 cal/rev;
~ 600 lbf / 0.001" @ 22.5 cal/rev
- "Max" CG offset ~ 0.010" (Yawsonde, wrt Bourrelets)
- Body Engraving Significantly Reduced in 30mm W/ Gain Twist BBLs
- Band Wear is a function of Band Melt Temperature

From H.P. Gay Report:



“Static” Force Model (Post Bounce)

$$aF_B = m \varepsilon \ddot{s} + m \varepsilon \dot{\alpha}^2 \lambda$$

$$F_R = \varepsilon/a [m\dot{\alpha}^2 (a - \lambda) - m\ddot{s}]$$

Where: ε = CG Offset
 s = Inbore Travel



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Engraving Model Theory

Body Engraving (BE) is the result of:

- Contact Stress Between Projectile & Gun Tube
- Duration of Contact Stress At Given Location on Projectile Bourrelet

Contact Stress is Determined by:

- Projectile Longitudinal Acceleration
- Spin^2
- Projectile Mass
- Barrel & Projectile Geometry
- Projectile Center of Gravity Offset WRT Barrel Centerline

Contact Location & Time is Determined by:

- Barrel Rifling Twist (Gain) & Land Geometry
- Band Wear
- Bourrelet Length
- Interior Ballistic Cycle



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Body Engraving Computational Approach

Use Previously Validated Computational Tools

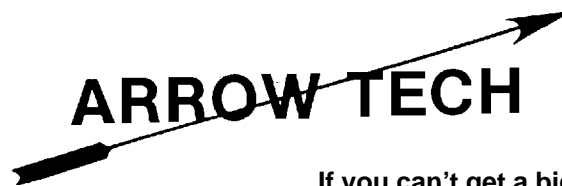
- Interior Ballistics Code (Modified Baer-Frankle / IBHVG2)
- Rotating Band Wear Analysis (e.g. Wolf-Cochran)

“Record Keeping” For Fwd Bourrelet Stress

- Divide Bourrelet into 4000 “Bins”
- Contact Location Reference vs. Time Known Prior to Run
 - » Function of Local Band Wear & Twist Angle
- Contact Area vs. Engraved Depth Known Prior to Run
 - » Engages Additional Bins as Body Engraves
 - »

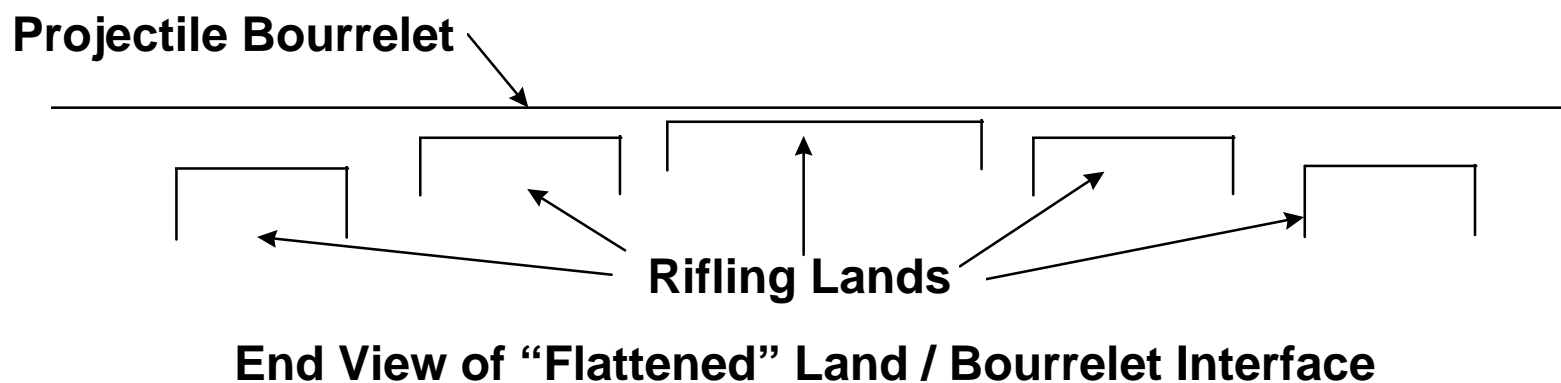
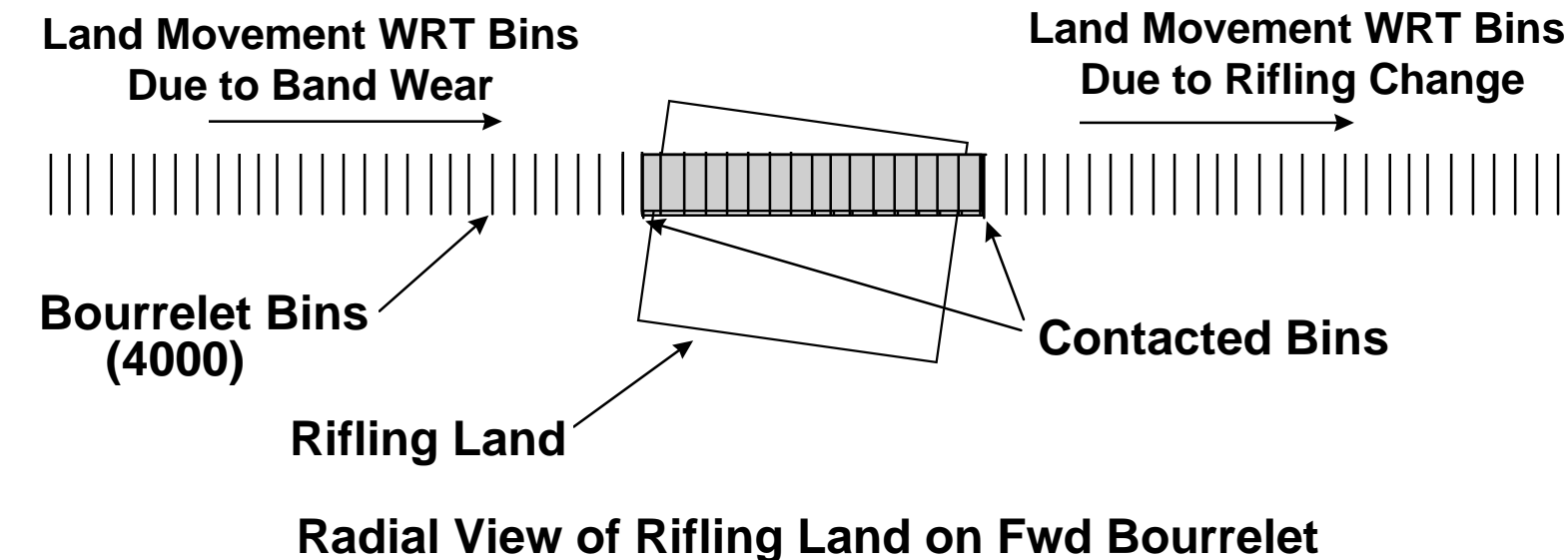
**If Stress-Time Product on Contacted Bins is Above
“Threshold”, Increment Engraving to Next Land Set**

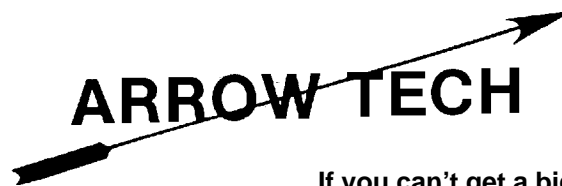




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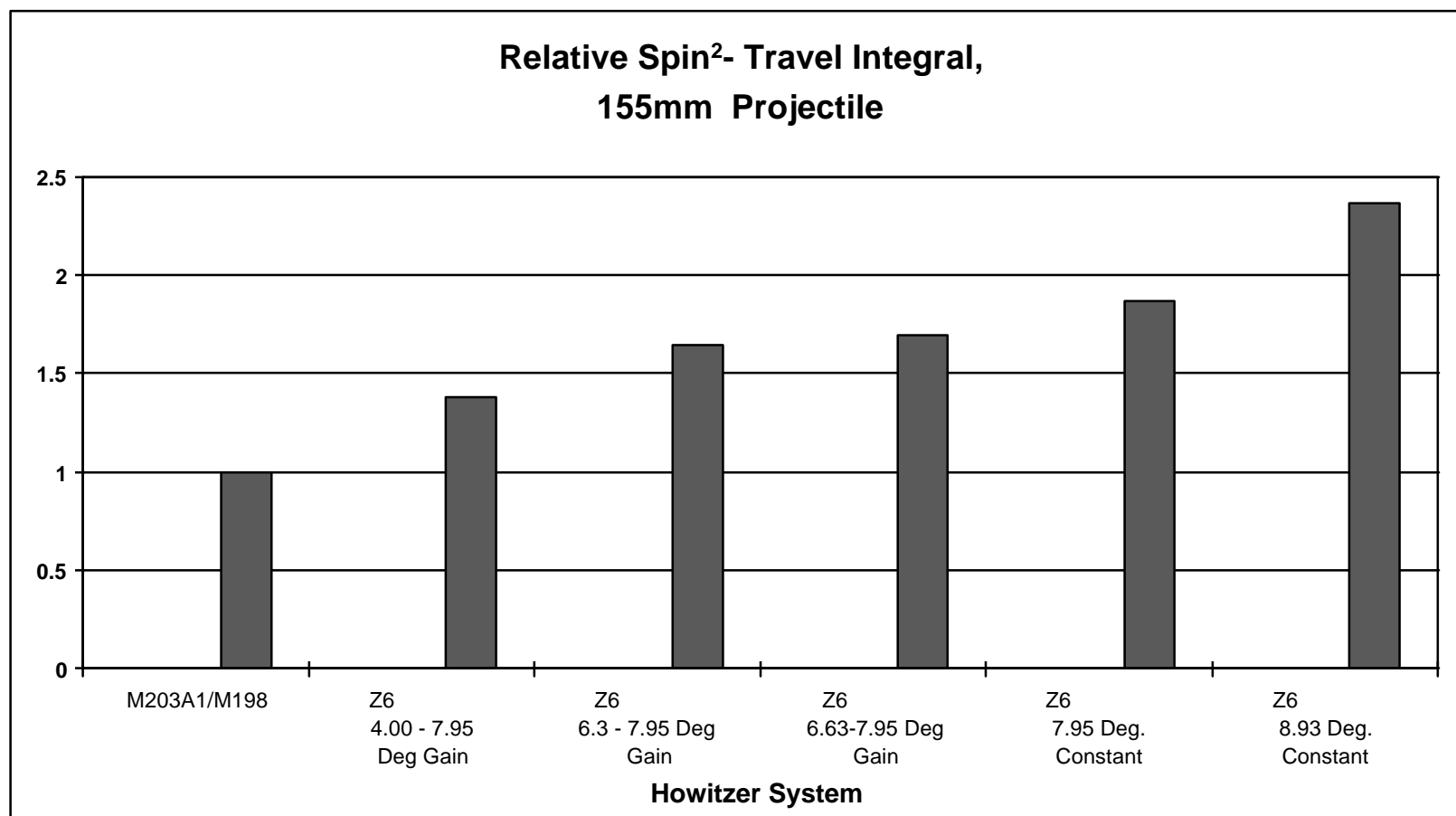
Engraving Model “Details”





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Comparison of Spin² Integral For Various Tubes





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Body Engraving Computational Model

- Read Initial Conditions
- Compute Contact Movement vs. Travel
- Compute Contact Area vs. Engraved Depth
- Compute Interface Geometry
- Step Thru Int. Ballistic Cycle, Accumulate Stress Time Product on Contacted Bourrelet Bins
- Increment Engraved Depth When Stress-Time Product Exceeds "Threshold"
- Compute New Interface Geometry (CG, Area)
- Continue Until Muzzle Exit
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Engraving Model “Calibration”

- **Large Caliber**

- Oct '97 155mm Test Firing Series
- 48 L&G Tube, Top Zone, 22.5 Cal/rev Constant Twist
- Steel Body Projectile Recovered w/ 0.005” Body Engraving

- **Medium Caliber**

- Late 70's Measured Body Engraving, GAU-8 Aluminum API
- Original 18 L&G Tube, 0.010” Thermal Expansion, Constant Twist
- Tactical 22 L&G Tube, 0.010” Thermal Expansion, 6.0-9.9 Deg Gain Twist

Assume: CG offset = 0.005” (Typical);

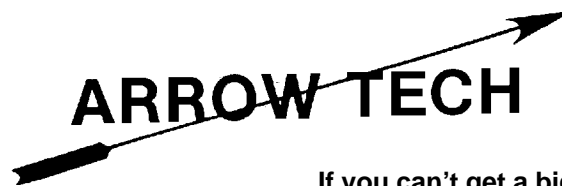
**Adjust Engraving Stress-Time Threshold
until Observed Engraving is Approximated**



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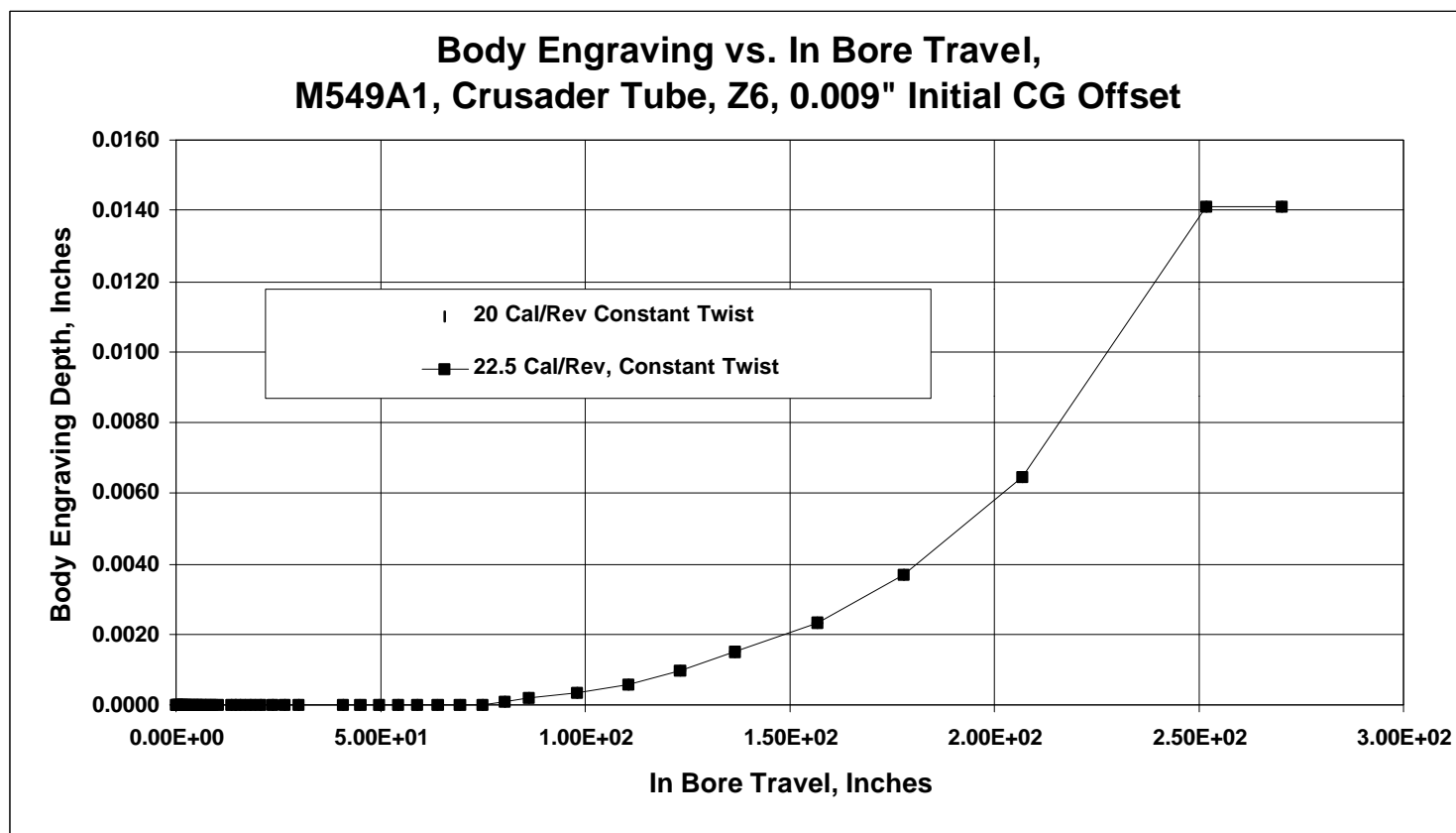
Use of Body Engraving Model

- **Effect of Reduced Exit Angle for Constant Twist Tubes?**
- **Effect of Number of Lands & Grooves on BE?**
- **Comparison of Constant Twist vs. Gain Twist Tube?**
- **Effect of Obturator/Band Leakage on BE?**
- **Effect of Gain Twist on BE with Leaks?**

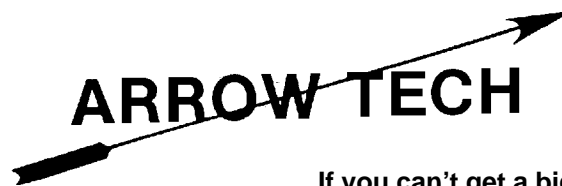


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Effect of Exit Angle For Constant Twist Tubes

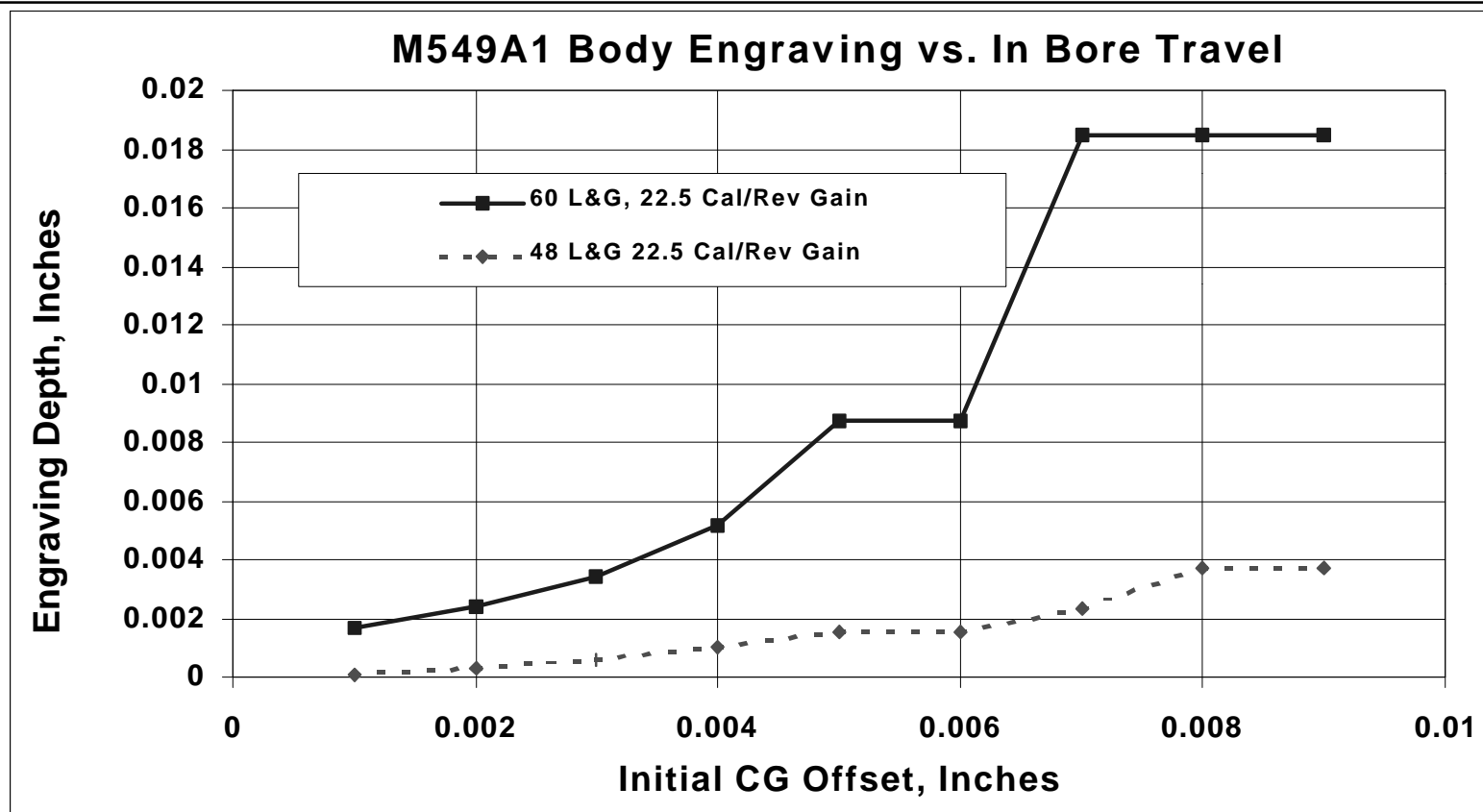


**Conclusion: No Body Engraving Benefit From Reduced Twist Angle
Due to Reduced Contact Point Movement**

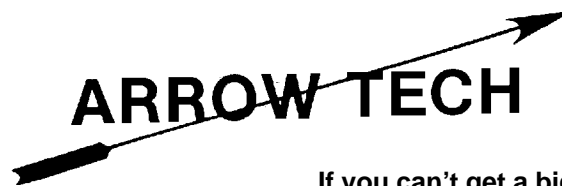


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Effect Of # L&G On Body Engraving

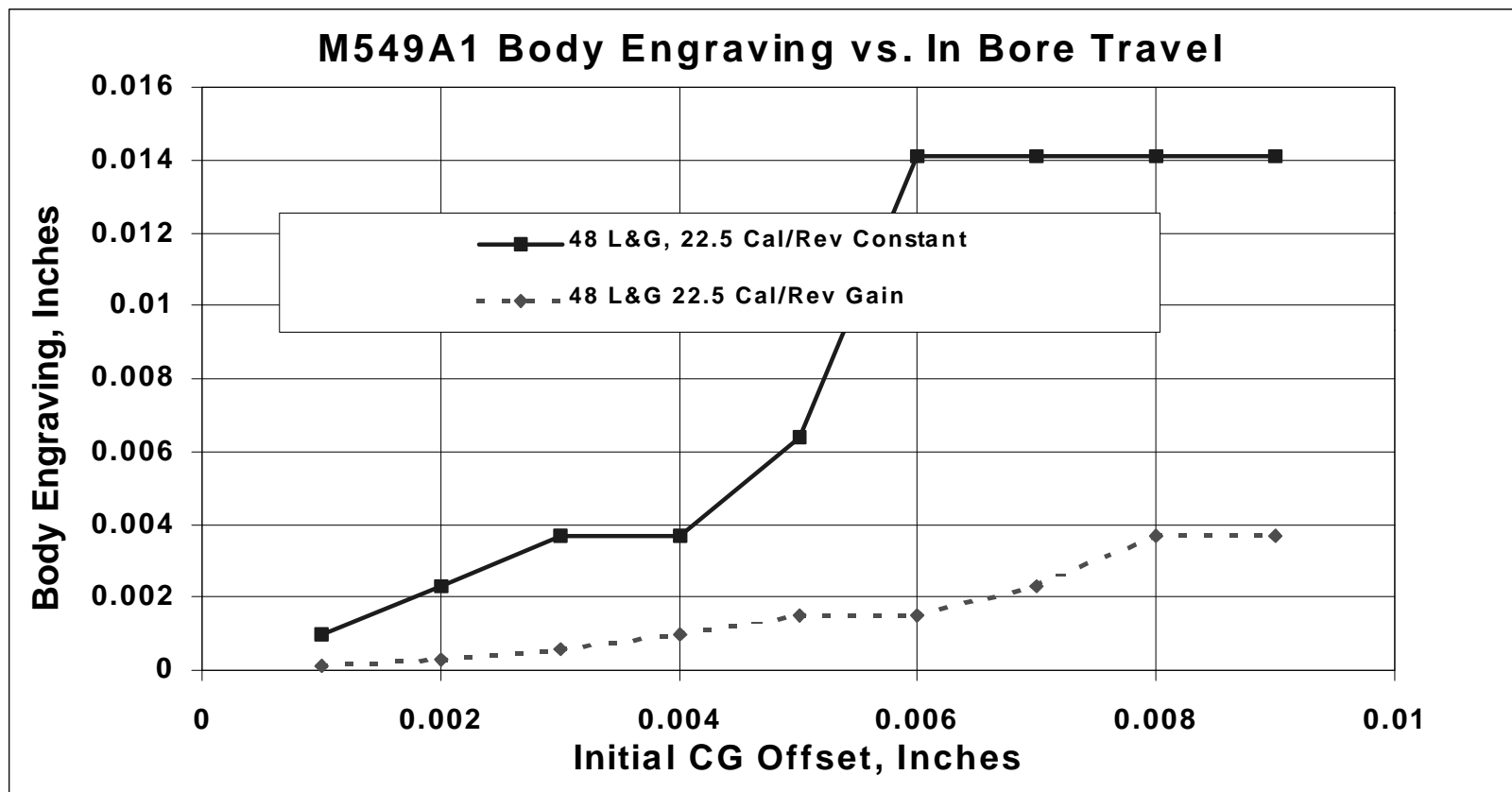


**Conclusion: More Lands & Grooves Increases Body Engraving
(w/ same G/L Width Ratio)**

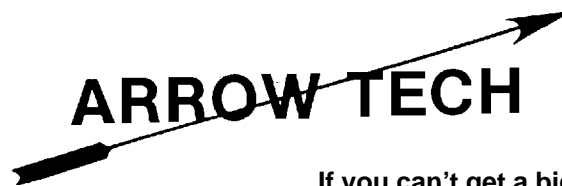


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Can Gain Twist Reduce Body Engraving?

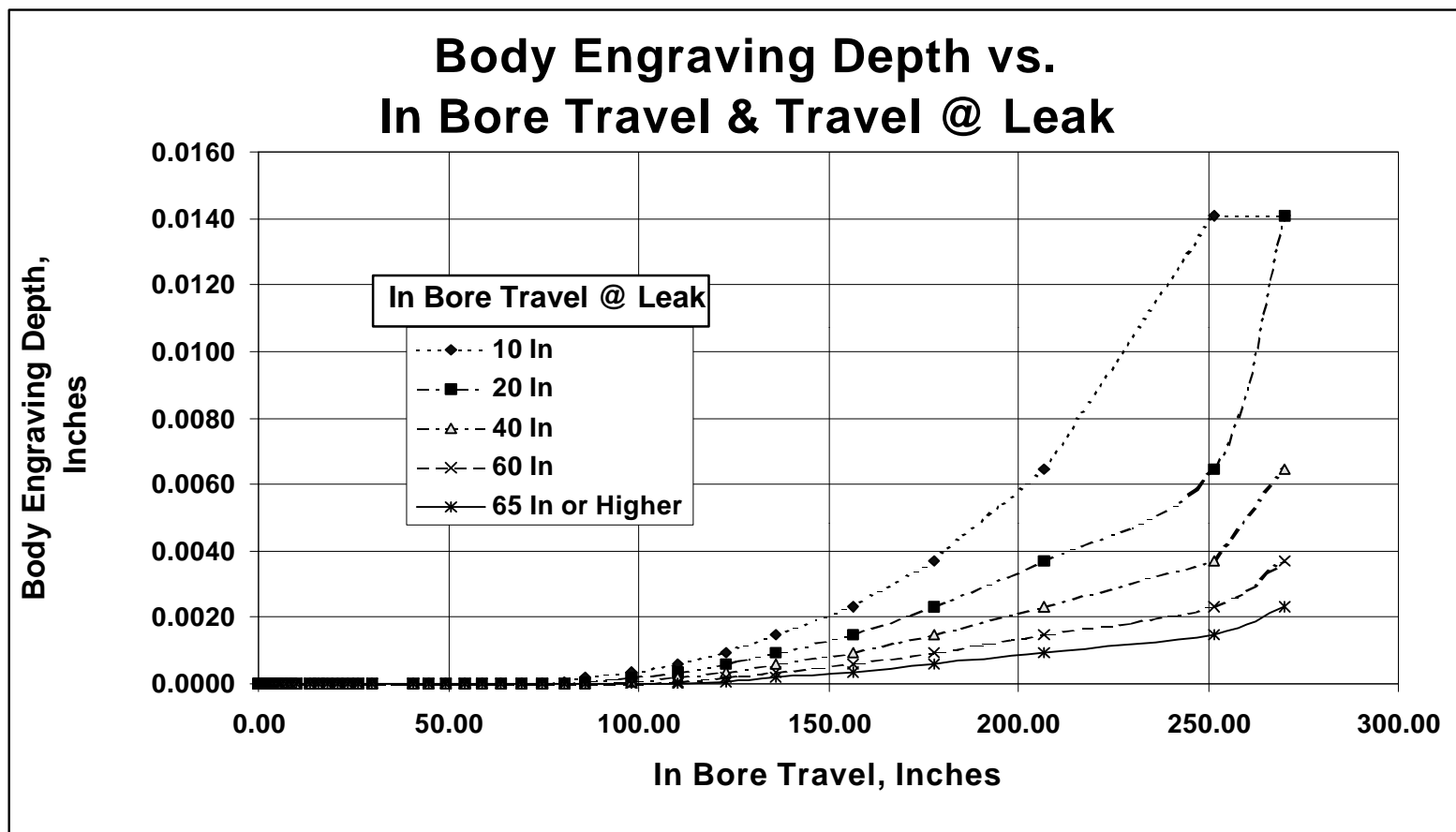


**Conclusion: For Fixed Exit Angle & Given Initial CG Offset,
Gain Twist Reduces Body Engraving**

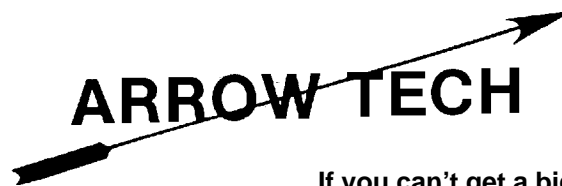


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Does Band Leak Affect Body Engraving?

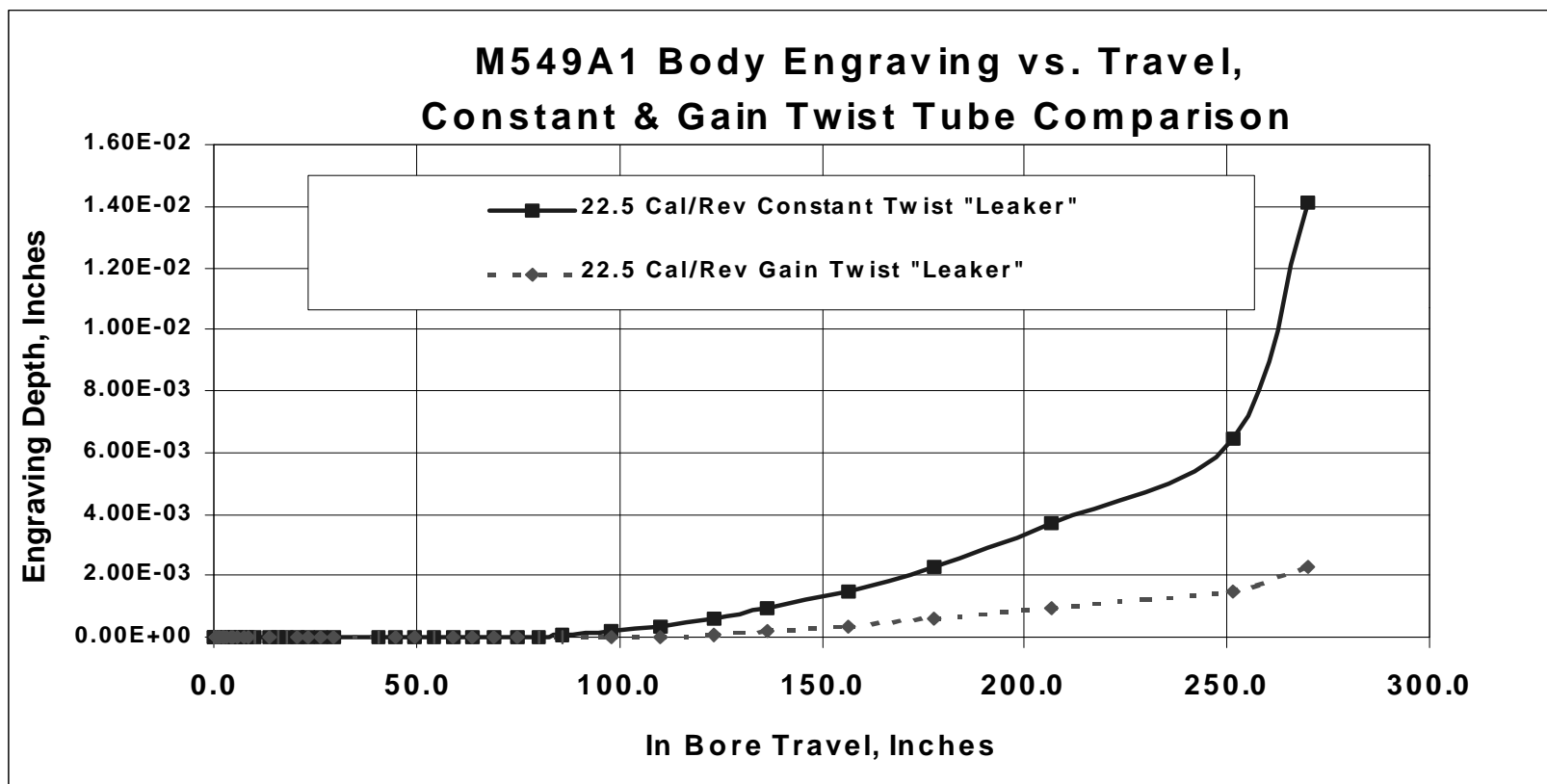


Conclusion: 1) Band Must Leak Early in Travel to Increase Body Engraving
2) Obturator Improvements Should Reduce BE Significantly



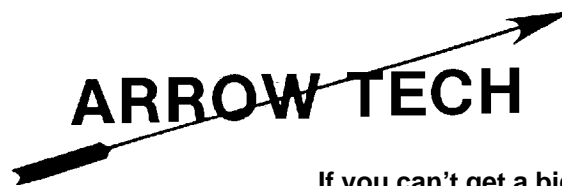
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Body Engraving Caused By Leakage With Constant & Gain Twist Tubes



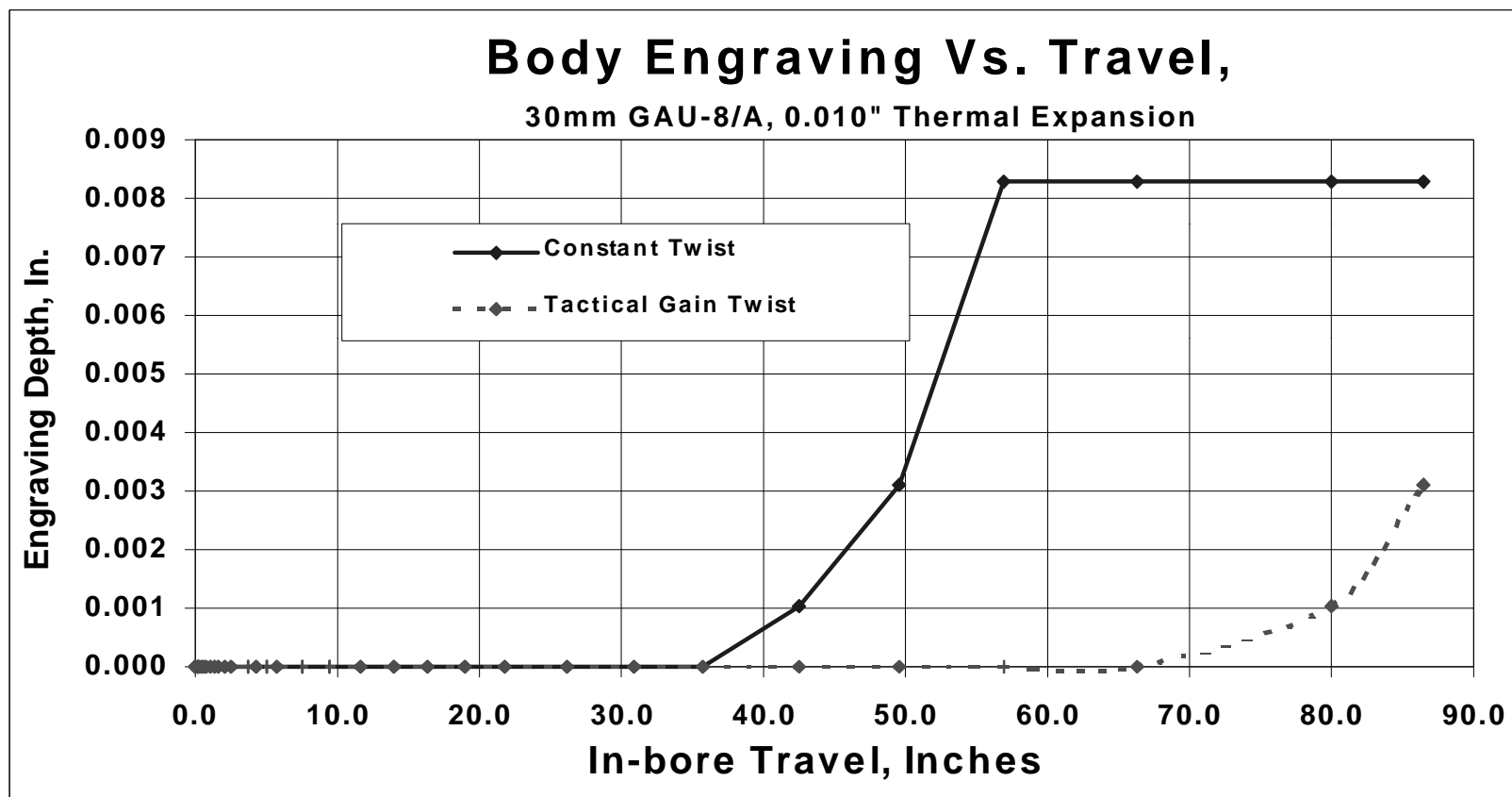
Conclusions:

1. Leak Must Occur Early in Travel to Increase Body Engraving
2. Gain Twist Reduces B.E. From Leaky Band/Obturator



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Medium Caliber Body Engraving



- Gain Twist is Critical to Prevent Body Engraving of Aluminum API Carrier
- Dispersion & Barrel Life Significantly Improved with Gain Twist Tube



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Observations

- **No Engraving Difference w/ Constant Twist Tubes**
 - 22.5 cal/rev & 20 cal/rev Constant Twist Tubes Have Same BE
 - Reduced Spin Load Offset By Reduced Contact Movement
- **Obturator Must Fail Early in Travel to Affect FWD Bourrelet Body Engraving in Artillery Projectiles**
- **Improved Gas Seals Should Significantly Reduce BE**
- **Gain Twist Reduces BE w/o Leaks**
- **Gain Twist Reduces BE w/ Leaks**
- **Lower # of L&G Reduces BE**



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Conclusions:

- **Simple File Construction, Rapid Computation**
- **Avoids FEM Re-meshing & Element Removal**
- **Body Engraving Model Predicts General Trends That Agree With Observed Body Engraving Behavior**
- **A Little Bit of Rifling Gain Goes A Long Way Preventing Body Engraving**
- **Rifling Profile Must Balance Contact Movement & Band Wear, Leakage Due to Band Wear is Critical**
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